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Contrast Training Generates Post-Activation Potentiation and Improves Repeated Sprint Ability in Elite Ice Hockey Players

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ABSTRACT

International Journal of Exercise Science 13(6): 183-196, 2020. The purpose of this study was to measure the generating effects of Contrast Training (CT) on 6-hour post-activation potentiation (PAP) and its influence on jumping and on on-ice repeated sprint performance in ice hockey players. Forty-one participants were divided in two groups: experimental (EG) and control group (CG). The EG followed the CT PAP protocol which consisted of 5 sets of 5 half inertia back squat superset with 6 squat jumps. The effects of PAP were measured with the vertical countermovement jump (CMJ), stationary broad jump (BJ) and 9 repeated on ice 40-meter maximal sprints with hockey equipment. Results showed that the PAP generated by the CT protocol had no significant impact ($p \geq 0.05$) on CMJ, BJ, blood lactate concentration, heart rate peak and rated perceived exertion as EG and CG group presented no significant differences in improvement. However, results show that there was a significant improvement ($p < 0.05$) for the EG in the total sprint time (-5.5 ± 2.6%; 56.2 ± 4.7 to 53.1 ± 3.9sec) mean sprint speed (+5.9 ± 3.0%; 6.4 ± 0.5 to 6.8 ± 0.5m/s) and in 1st sprint speed (+7.4% ± 5.9; 7.3 ± 0.7 to 7.8 ± 0.6m/s), but not for the CG (-1.4 ± 5.1%; 58.0 ± 5.4 to 57.2 ± 6.4sec), (+1.7 ± 5.1 %; 6.3 ± 0.6 to 6.4 ± 0.6m/s) and (+1.9 ± 7.7%; 6.9 ± 0.7 to 7.0 ± 0.7m/s) respectively. Thus, results show that the CT protocol utilized in this study generated PAP which had an acute effect on the on-ice hockey repeated sprint test performance. Therefore, CT could be utilized punctually to improve repeated sprint performance of elite hockey players as it could potentially help create odd man rushes during games.

KEY WORDS: Resistance training, complex training, skating speed, plyometric, rate of force development

INTRODUCTION

Ice hockey is one of the most physically and physiologically complete sports (48). It requires its players to develop agility, power and excellent stick handling as well as being ready to give and absorb physical contact (16, 64). Particularly for these reasons, strength and conditioning coaches can be a great asset for players trying to increase their physical performance.

Several training methods have already shown to help increase strength and power among athletes (26, 33, 68). One of these methods consists of training with relatively heavy loads (80 - 90% of 1 RM) since it has been shown that a greater increase in muscle power and strength occurs than when working with lighter loads (29, 58). Another method that has shown to increase an athlete's power and rate of force development (RFD) is plyometric training (3, 15, 17, 40). In fact, this method has led to improvements in strength, speed, power, change of direction, balance, and jumping performance in dynamic movements, such as sprinting ability, by improving storage and utilization of elastic strain energy, increasing involuntary nervous reflexes, enhancing length-tension characteristics, motor coordination and muscular pre-activity (4, 5, 8, 22, 39, 41, 43, 45).

A more recent concept known as post-activation potentiation (PAP) has emerged as a way to quickly increase an athlete's power development over a short period of time and is defined by Robbins (56) "as a phenomenon by which the force exerted by a muscle is increased due to its previous contraction". Thereby, PAP increases the excitability of the central nervous system and produces an increase in contractile function due to a heavy load stimulus (55). PAP is typically induced from maximum voluntary concentric and eccentric contractions, as well as submaximal isometric contractions (47). Hence, generating PAP through specific training protocols prior to competition, for example, increasing performance in hockey players, could be a better option to conventional warm-up techniques, as it could enhance performance in explosive sports (25). Nonetheless, it must be indicated that the training protocol used is important since fatiguing muscle contractions might impair muscle performance, but non-fatiguing brief muscle contractions under heavy loads could enhance muscle performance (60). In other words, strength training fatigue has to dissipate at a faster rate than PAP effects so that a potentiation of a subsequent explosive performance can be realized within the recovery window (62).

Although the majority of the literature shows that the PAP effects last between 5-30 minutes (18, 24, 25, 32, 36, 56, 66), some other publications state that it's neural effects could last between 6 and 24 hours (6, 10, 11, 19, 23, 53, 63). To this day, it is clear that many factors have to be taken into account when trying to induce PAP. Despite PAP's current popularity; no studies have examined the effectiveness of Contrast Training (CT), which combines weight training and plyometric, the day of an ice hockey game. Complex training or CT method is a term credited to Verkhoshansky and developed by track and Field coach Gilles Cometti (13, 65). This method consists of combining a heavy compound exercise (80% 1 RM) followed by a plyometric movement that has similar biomechanical characteristics (56).

The purpose of this study was to measure the acute response coming from the generating effects of CT on PAP and its influence on power development over a longer period of time. Thus, the hypothesis of this study was that conducting a CT protocol 6 hours prior to a power activity would generate post-activation potentiation that would improve performance on vertical counter movement jump (CMJ), broad jump (BJ) and on-ice repeated sprint performance on elite midget and junior ice-hockey players. This hypothesis was based on previous work that demonstrated the PAP phenomenon could last between 6-24 hours compared to the traditional PAP window (less than 30 minutes) (11, 12, 19, 23, 50, 63). We believe that this training modality will exhibit more favorable outcomes in measures of hockey performance by increasing the rate of force development (RFD) compared to other training modalities. Also, the time frame chosen in this study (6 hours prior testing) correspond best with the "game day" routine of a hockey player. Additionally, Moreover, Cook et al. (14) and Bompa and Buzzichelli (6) have already illustrated the benefits of resistance training the morning six hours before a competition. The results of this study could lead to strength and conditioning coaches working with hockey players utilizing PAP as a tool to increase on ice repeated sprint performance the day of the competition.

METHODS

Participants

Subjects (n = 41) participating in this study were elite midget or junior hockey players (Midget AAA or QMHJL), that were at least 15 to 21 years of age (16.63 ± 1.51yrs) with a minimum of 1 year of strength training experience (2.88 ± 1.50yrs). Following the preliminary testing session, participants were assigned to EG (n = 21) or CG (n = 20). Prior to data collection, an ethical certificate (IRB No 1508) was obtained through the University of Quebec at Montreal's (UQÀM) institutional review board committee. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (49). All participants were voluntary subjects that received no financial compensation and signed an informed consent. Participant's less than 18 years of age had the waiver signed by their parents or guardian. Both group's characteristics are presented in Table 1.

Table 1. Experimental and Control Group Characteristics.

	Experimental Group (n = 21)	Control Group (n = 20)
Age (years)	16.8 ± 1.3	16.4 ± 1.7
Height (cm)	177.3 ± 6.1	181.6 ± 5.3*
Weight (lbs)	166.8 ± 8.6	169.6 ± 7.3*
BMI (kg/m²)	24.1 ± 2.0	23.6 ± 2.1
Body fat %	11.1 ± 1.7	13.4 ± 3.4
Lean body mass (lbs)	145.6 ± 6.8	145.6 ± 6.4
Strength training experience (years)	3.4 ± 1.6	2.3 ± 1.2*

Note. Values are means (SD); * indicates Control Group significantly different at $p < .05$

In this controlled study, the majority of the subjects with a lower body fat percentage were in the EG group with an estimated 1RM of 151.3 ± 26.7 kg and a relative strength ratio of 1.78 (kg of weight squatted/kg of bodyweight). The estimated 1RM was measured with the Brzycki formula (9). The attribution of EG vs CG (responder's vs non-responders) participants was made to increase the chances of success utilizing a training modality to increase potentiation prior to competition. Therefore, it is important that strength and conditioning coaches expect CT PAP method to be more effective on athletes that have a higher relative strength ratio (minimum 1.5 x bodyweight) compared to those with an inferior relative strength ratio (36). Previous investigations have shown that body composition is related to a hockey player's performance (51), that excess body fat decreases functional capacity and athletic performance (46), that the relative strength (weight/body weight) of the athlete would be a predictor for effectively using the PAP method (12, 30, 34) and that the level of training of athletes has been shown to be a good predictor of PAP performance (12). One of the factors that may explain these results would be the conditioning of the athletes who are predisposed to be more resistant to fatigue will require shorter rest periods following a weight training session with 80% 1RM (54).

Protocol

This study was designed to examine the effect of a CT PAP generating protocol on jumping and on ice hockey player's repeated sprint performance. Experimental design consisted of two groups, experimental (EG) and control (CG), matched for skill level and a minimum of resistance training experience undergoing pre-and post-intervention measures to examine the effect of PAP on jumping and on-ice repeated sprint performance. During the pre-testing session, both groups' jumping and repeated sprint performance were assessed. During the post-testing session (72 hours later), the same assessments were run with EG executing a CT session 6 hours prior to the testing session. PAP effect was then measured by comparing both group's results and improvement difference.

Data collection was conducted in February 2017, at this time of the year; subjects would attend 10 hours of on ice practice (2:00-4:00 PM Monday-Friday) with 2 hours of strength training (Tuesday and Wednesday from 12:45-1:45 PM). Participants were asked to not train 48 hours prior, although no instructions were given regarding nutrition and beverage restrictions before protocol. Both groups had their performance measures taken at the same time of day, i.e., in the evening (around 7:00 PM ET) to mimic evening hockey game conditions.

At the start of the first testing session, participant's height, weight and body fat % were measured before performance tests. Body fat % was estimated with 10 skinfolds (chin, cheek, pectoral, triceps, mid axillary, supra-iliac, umbilical, subscapular, knee and calf) with the Zwiren & Allen equation sites (1, 69). The BJ was measured with a method of having subjects stand stationary behind a line and jumping distance was measured from toes (line) to the closest heel and CMJ jump height was measured using a Bosco mat (37). For the CMJ, the participants would bend their knees and lower their arms to jump as high as they could while keeping their legs straight. The Bosco mat measured jump height through flight time. The best of 2 attempts was retained for each jump test. These off-ice tests have a direct applicability of the lower body muscular power and have a direct ability to measure dynamic muscular power which is associated with on-ice performance in speed and skating acceleration in elite hockey players (20, 31, 35, 38). Following the jump testing session (CMJ & BJ), participants had 15 minutes to put on all their regular hockey gear (ex: Underwear, socks, shin guards, shoulder pads, elbow pads, skate, hockey pants, helmet, gloves etc.) before the repeated sprint test. The on-ice repeated sprint test included 9 sprints of 40 m each (approximately 5 seconds) interspersed with 3 seconds of recovery which allowed the subjects to execute a 180° turn in order to return to the finish line, which would now become the starting line of their next sprint. This test mimics a hockey player's typical shift which lasts between 30 and 80 seconds and involves intermittent work with maximal-intensity efforts of 3-5 seconds alternated with low-intensity efforts where the player glides on the ice (16, 48, 52). The 40-meter sprint distance is equivalent to almost 2/3 of an ice rink (61 meters) and represents a hockey player getting puck possession deep in their defensive zone and entering the offensive zone (7). In addition, a total of 9 repeated sprints allowed increasing significance of fatigue index.

Sprint performance was measured with photo cells timing gates, placed at the start and at the end of the test at 0- and 40-meter lines. The side start was the starting position for all the repeated sprints. Heart rate monitoring was done using a heart rate monitor (RS400, Polar, FI). After completing the 9 repeated sprints, the players rated their perception of effort using a Borg scale and then a lactate (Lactate Pro, Akray, Japan). Lactate measurement was performed using a capillary blood sample taken from the participant's left index finger 3 min after all the repeated sprints test in a seated position. At the end of the last sprint, the subjects were instructed to decelerate, and then skate back to the player bench to sit and wait for the fingertip sampling. Indeed, Taoutaou et al.(61) reported that post-exercise peak [La] was attained at approximately 3 min post-exercise when no active recovery was performed.

Following the first session, participants were divided into two groups: experimental group (EG) and control group (CG). The EG was composed of the participants who had the highest average score in the long and vertical jump in the first session. The EG group characteristics selection was based on current literature research that have demonstrated that individuals obtaining better results at the vertical (CMJ) and broad jump (BJ) test generally possess a higher proportion of type 2 fibres and therefore have a greater potential to respond to PAP in a targeted muscle group (2, 27, 28).

The EG performed the CT PAP generating protocol six hours prior to second testing session. The protocol had subjects execute a superset of 5 sets of 5 repetitions (85% 1RM) of inertia back squat with a 4-X-0-1 tempo followed by 6 squat jumps and 180 seconds of rest. The subject's 1RM was estimated based on their previous individual weightlifting sessions and corrected with a predicted 5RM that was used during the warm-up. The warm-up consisted of four sets: the first set with 8 reps at 50% of 5RM, second set with 6 reps at 65% of 5RM, third set with 5 reps at 80% of 5RM and the fourth set with 5 reps at 90% of 5RM. The process consisted of trials and errors to establish a starting weight as close as possible to the 5RM of the athlete. The squat rack safety pins were set so that participants would squat to 90°of knee flexion before setting the barbell on the pins to control the inertia and the range of motion of each repetition.

The third session, which took place 72 hours after the first, involved the participants repeating the BJ, CMJ and on-ice repeated sprint tests as previously stated. A mandatory warm up was performed before each of the 3 sessions and is presented in Table 2. A summary of the experimental procedures and its schedule are presented in Table 3.

Please note that even if groups had a significant difference in starting capabilities, this research was able to compare across groups since the statistical analysis was performed for Intra (within) group comparisons. In fact, the statistical analysis model was based on a two factor (time x group) ANOVA for repeated measures. Thus, the within group analysis for CMJ and BJ across time in both groups was not significantly different, but the Inter group analysis revealed that at time 1 (pre-intervention) a significant difference between groups was present because of their starting capabilities.

Table 2. Dynamic Warm-up.

Exercise	Sets (No)	Distance (m)	Time (sec)
Light jogging	1	20	120
High knees	2	20	30
Heels to butt	2	20	30
Carioca	4	20	60
Dynamic lunges with rotation	2	20	30
Hip rotation	4	20	60
Lateral lunges	4	20	60
Backward lunges reach and twist	2	20	30
Leg swings	2	20	60
Front tuck to sprint	6	20	120

Table 3. Experimental procedures.

Day	Time	Session	Groups	Tests
Day 1	7:00 pm	Session 1	Experimental Control	Height Weight Body fat % Vertical jump Broad jump Repeated sprint test
Day 2	1:00 pm	Session 2	Experimental	Contrast training session
	7:00 pm	Session 3	Experimental Control	Vertical jump Broad jump Repeated sprint test

Statistical Analysis

Results are presented as means (AVG) and standard deviation (SD). Since our sample was made of a total of 41 participants distributed into two groups, the Shapiro-Wilk test was used to verify normality distribution within groups. The sample size was based on a 5% improvement on the primary outcome measure of sprint 1 speed (see Table 4). Based on pre and post intervention improvement (one-sided) in average sprint 1 speed and pooled SD, it was calculated that at a sample size of 20 per group would yield a statistical power (β) of at least 0.8 using an alpha of 0.05. Anthropometric measurements of both groups were compared with independent samples t-tests, while the differences between the control and experimental groups were calculated using a two factor repeated measures ANOVA (Group X time). If a difference was detected, a *post hoc* test was conducted for pairwise comparison using a Bonferroni correction. Significance was set at $p < 0.05$. All statistical analyses were conducted with SPSS software (version 21).

RESULTS

There was no significant difference ($p \geq 0.05$) between pre-and post CMJ test results for EG (+0.1; 69.8 to 69 cm) and CG (+2.2%; 58.0 to 59.2 cm). There was a significant difference ($p < 0.05$) between pre-and post BJ test results for the EG (+4.8%; 254.1 to 266.3 cm) and CG (+3.0%; 230.6 vs 237.4 cm). Most importantly, there was a significant improvement ($p < 0.05$) for the EG in the total sprint time (-5.5%; 56.2 to 53.1 sec) mean sprint speed (+5.9%; 6.4 to 6.8 m/s) and in 1st sprint speed (+7.4%; 7.3 to 7.8 m/s), but none for the control group (-1.4%; 58.0 to 57.2 sec), (+1.7%; 6.3 to 6.4 m/s) and (+1.9%; 6.9 to 7.0 m/s) respectively. Blood lactate concentration, heart rate peak and rate of perceived exertion (RPE) did not significantly improve ($p \geq 0.05$) for EG (-4.9%; 13.0 to 11.1 mmol*L^{-1}) (-0.2 %; 158.2 to 156.2 bpm) (+7.3 %; 13.2 to 13.9 Borg$_{6\text{-}20}$) and CG (-2.2%; 12.4 to 11.6 mmol*L^{-1}) (-0.9 %; 158 to 157 bpm) (+3.9%; 13.7 to 14.1 Borg$_{6\text{-}20}$). All performance testing results are presented in table 4.

Table 4. Physical and physiological responses before and after post activation potentiation.

	Experimental Group (EG)			Control Group (CG)			EG % Improvement Difference to CG
	Pre	Post	(%Δ)	Pre	Post	(%Δ)	
Vertical jump (cm)	69.8* ± 6.6	69.7* ± 5.9	-0.1 ± 5.9	58.0 ± 4.7	59.2 ± 4.9	+2.2 ± 5.5	-2.1
Broad jump (cm)	254.1* ± 17.2	266.3*† ± 19.2	+4.8† ± 4.6	230.6 ± 9.7	237.4† ± 11.3	+3.0† ± 3.9	+1.8
Total sprint time (sec)	56.2 ± 4.7	53.1*† ± 3.9	-5.5*† ± 2.6	58.0 ± 5.4	57.2 ± 6.4	-1.4 ± 5.1	-4.1
Mean sprint speed (m/s)	6.4 ± 0.5	6.8*† ± 0.5	+5.9† ± 3.0	6.3 ± 0.6	6.4 ± 0.6	+1.7 ± 5.1	+4.3
Sprint 1 speed (m/s)	7.3 ± 0.7	7.8*† ± 0.6	+7.4† ± 5.9	6.9 ± 0.7	7.0 ± 0.7	+1.9 ± 7.7	+5.5
Lactate (mmol*L^{-1})	13.0 ± 4.3	11.1 ± 2.6	-4.9 ± 40.3	12.4 ± 4.4	11.6 ± 3.2	-2.2 ± 36.3	-2.7
HR$_{PEAK}$ (bpm)	158.2 ± 14.5	156.2 ± 13.1	-0.2 ± 14.9	158 ± 18.9	157 ± 19.1	-0.9 ± 17.9	+0.7
RPE (Borg$_{6\text{-}20}$)	13.2 ± 2.5	13.9 ± 2.1	+7.3 ± 18.8	13.7 ± 2.0	14.1 ± 2.2	+3.9 ± 16.5	+3.4

Note. *significantly different to control group, $p < 0.05$; † significantly improved (Pre to Post), $p < 0.05$; Mean (SD); %Δ indicates percent difference between pre-and post; Bold characters indicate significant differences. HR$_{PEAK}$: Heart Rate Peak; RPE: Rate of Perceived Exertion

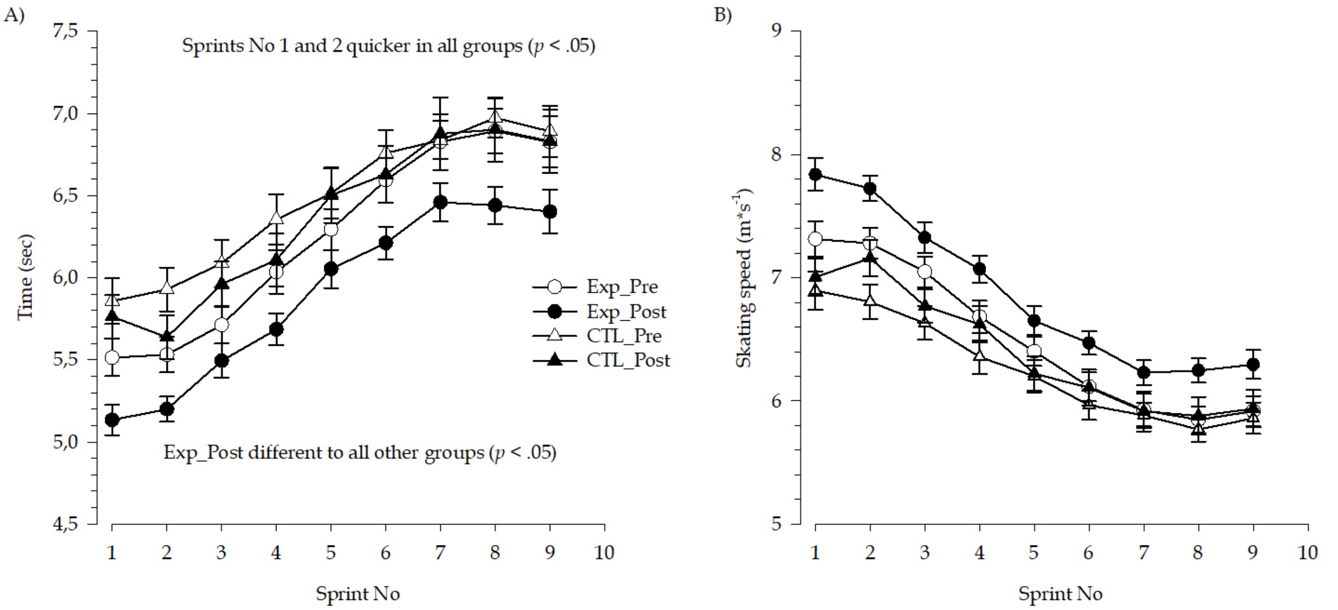

Figure 1. The effect of CT on repeated sprint time and speed. A) Sprint time (sec) as a function of sprint number (No). Sprint No 1 and 2 were significantly quicker in all groups regardless of pre or post CT (top dark horizontal bar). In the Exp (experimental group) the post CT sprint time was quicker for all sprints No when compared to all other groups (bottom dark horizontal bar). B) Skating speed (m^*s^{-1}) as a function of sprint number (No). Similar to A), Sprint No 1 and 2 were significantly quicker as well as the Exp_post for all sprints No when compared to all other groups. Each data point represents mean and error bars are SEM. Circles represent Control Group (CTL) pre (white) and post (black). Triangles represent Experimental Group (Exp) pre (white) and post (black).

DISCUSSION

The main finding of this study is that contrast training completed six hours prior to an on-ice repeated sprint test induces PAP and reduces elite ice hockey player's total sprint time, improves their average speed and 1st sprint speed. This was confirmed by the fact that all participants seem to have provided the same effort (no significant difference between the two groups, pre-and post-intervention, for blood lactate, heart rate, and score on the Borg scale). Thus, the improvements observed in the repeated sprint test seem to be generated by the induced PAP coming from an acute response due to the CT protocol and not by a variation in motivation or intensity of execution during the pre-and post-intervention tests.

The BJ significantly improved (+4.8%) in the EG group and were significantly different from CG. This power metrics tests (BJ) increased speed/time on-ice performance sprints test as concluded in the PAP literature (31, 35, 38). Comparing 1st sprint speed percentage point difference in improvement (+5.5%) between EG and CG would have a hockey player from the EG reach the offensive zone (40m mark) 2.09 m ahead of his opponent from the CG group who did not execute a CT protocol. This means that a player creating an odd-man rush will have more room and time to make a decision with the possession of the puck. Comparing mean sprint speed percentage point difference in improvement (+4.3%) between EG and CG group would mean that after 5 sprints, toward the end of the shift, the player from the CG would be 8.25 m behind the EG PAP facilitated player. This means that a team having all of its players from the

EG competing against players from the CG, could be first on the puck and creating more odd-man rushes as the play continues. However, even though results of the present study show that contrast training can help increase performance in repeated sprints with hockey players, we cannot conclude that the duration of this phenomenon will carry on for an entire game as the test conducted in this study only included 9 repeated 40-metre sprints.

CT could be viewed as a more effective training protocol since it combines two training methods that have the potential to increase PAP: strength training and plyometric. The CT involves heavy and slow strength training exercises along with explosive and light exercises and therefore would be more effective in increasing potentiation by post-activation (12). Additionally, the effect of CT method has already been proven on subsequent ice-hockey sprint performance with heavy bands resisted right before sprints with a short rest window of 4 minutes (44). Moreover, Cook et al. (14) illustrate the benefits of resistance training the morning six hours before a competition, and could lead to an increase in performance. Furthermore, Bompa and Buzzichelli (6) found that training with a load over 80% of subject's 1RM leads to a potentiation 6 to 7 hours later and its effects could last up to 24 hours. As well, González-Badillo et al. (23) observed that a low volume protocol of 3 sets of 4 repetitions at 80% 1RM will result in a faster recovery of performance (within 6 hours). Others studies, found that a short resistance training session in the morning resulted in a small-to-moderate (1.3 - 2.7%) improvement in explosive muscle performance 6 hours later that could last 48 hours when fatigue is minimized (10, 14, 19, 45, 53, 63).

To this date, the theories and methods used to increase PAP have shown negative and positive effects on performance, and their benefits are often observed in a very short time window: between 5 and 30 minutes (18, 24, 25, 32, 36, 42, 56, 66). The current research adds to the present literature by showing that the PAP benefits are still present 6 hours after a training protocol.
The improvement in the skating speed of the hockey players could be explained by the activation of the nervous system that may increase muscle excitability resulting from a voluntary contraction induced by the heavy squats that were performed six hours prior to testing (54). This neuromuscular ability is related to the muscle fiber recruitment efficiency of the trained group to produce the desired movement with explosion and power (65). The improvement in performance can also be explained by the physiological phenomena of the phosphorylation of myosin light chain, the proportions of fast-twitch muscle fibers and the density of sodium-potassium pump in the muscles. In fact, Docherty and Hodgson (21, 40) explain that all of these phenomena could help optimize performance during post-activation potentiation activity, since they allow fatigue to disappear faster than the potentiating effects (59).

As mentioned previously, the results of this study showed that 6 hour PAP did have an effect on on-ice repeated sprint performance when comparing EG to CG results, but not on jumping performances. The majority of the studies directed towards PAP included a vertical jump or sprints instead of a squat jump following the back squat since the energy transfer is better biomechanically and physiologically (24). Similarly to the present study, Scott and Docherty (59), observed no increase in broad jump and vertical jump performance following a 5RM back squat with subjects with at least 1 year of experience in strength training. Therefore, it would be interesting to see if the combination of a back squat and plyometric jump with the identical movement (squat jumps) six hours earlier would cause excessive local muscular fatigue considering that both movements require rapid force at the levels of the extensors at the hips and knees (squat jump vs vertical jump). Another study utilizing a different jumping protocol could also have shown PAP effect on vertical jump performance. It is also possible that the time widow allocated (6 hours) in the present study could have been too long to observe the benefits of the potentiating effects on jump performance. Thus, we could reduce the time window to 3 hours for the recovery of skeletal muscle contractility after high- and moderate- intensity strength exercise (53).

The results presented in this study could lead to further research trying to understand why CT protocol did have an effect on repeated sprint performance, but not on jumping performance. Also, performing muscular biopsies following this research would help clarify the physiological response to CT which helps increase performance through potentiation. The analysis of the muscular tissues collected could potentially reveal certain mechanisms that can support the use of this method and increase performance in hockey players for the entire duration of their game (57, 67). Nevertheless, strength and conditioning specialists who will be utilizing the CT method the day of a competition will have to carefully adjust the protocol parameters in order to optimize the effects of PAP.

In conclusion, this investigation was able to demonstrate that hockey players that underwent a CT protocol six hours prior to on-ice repeated sprint testing improved their performances: reducing total sprint time, improving mean sprint speed as well as 1st sprint speed. The hypothesis of this study was that conducting a CT protocol 6 hours prior to power activity would generate post-activation potentiation and would improve performance on CMJ, BJ and repeated sprint performance on elite junior ice hockey players. Results showed that PAP generated by the CT protocol had no significant impact on jumping performance but impacted significantly repeated sprint performance. Therefore, the hypothesis is partially rejected.
Thus, results show that the contrast training protocol utilized in this study (5x5 @ 5RM Back Squat superset with 6 squat jumps) induced an acute PAP response on repeated sprint performance over a 6-hour time frame and is a good tool that could be utilized punctually by strength and conditioning coaches working with elite hockey players as it can help create and build odd-man rushes.

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REFERENCES

1. Allen TH, Peng M, Chen K, Huang T, Chang C, Fang H. Prediction of total adiposity from skinfolds and the curvilinear relationship between external and internal adiposity. Metabolism 5: 346-352, 1956.

2. Andersen LL, Andersen JL, Zebis MK, Aagaard P. Early and late rate of force development: Differential adaptive responses to resistance training? Scand J Med Sci Sports 20(1): e162-e169, 2010.

3. Behrens M, Mau-Moeller A, Bruhn S. Effect of plyometric training on neural and mechanical properties of the knee extensor muscles. Int J Sports Med 35(2): 101-119, 2014.

4. Bobbert MF, Gerritsen KG, Litjens MC, Van Soest AJ. Why is countermovement jump height greater than squat jump height? Med Sci Sports Exerc 28(11): 1402-1412, 1996.

5. Bojsen-Moller J, Magnusson SP, Rasmussen LR, Kjaer M, Aagaard P. Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. J Appl Physiol 99(3): 986-994, 2005.

6. Bompa T, Buzzichelli C. *Periodization training for sports, 3e*. Human Kinetics Publishers; 2015.

7. Books T. *Official rules of the nhl*. Triumph Books (IL)Publishers; 2005.

8. Bosco C, Komi PV, Ito A. Prestretch potentiation of human skeletal muscle during ballistic movement. Acta Physiol Scand 111(2): 135-140, 1981.

9. Brzycki M. Strength testing—predicting a one-rep max from reps-to-fatigue. J Phys Educ Recreat Dance 64(1): 88-90, 1993.

10. Chen J-L, Yeh D-P, Lee J-P, Chen C-Y, Huang C-Y, Lee S-D, Chen C-C, Kuo TB, Kao C-L, Kuo C-H. Parasympathetic nervous activity mirrors recovery status in weightlifting performance after training. J Strength Cond Res 25(6): 1546-1552, 2011.

11. Chiu LZ, Fry AC, Schilling BK, Johnson EJ, Weiss LW. Neuromuscular fatigue and potentiation following two successive high intensity resistance exercise sessions. Eur J Appl Physiol 92(4-5): 385-392, 2004.

12. Chiu LZ, Fry AC, Weiss LW, Schilling BK, Brown LE, Smith SL. Postactivation potentiation response in athletic and recreationally trained individuals. J Strength Cond Res 17(4): 671-677, 2003.

13. Cometti G, Joly B. *Les méthodes modernes de musculation*. Presses de l'Université de Bourgogne Publishers; 1989.

14. Cook CJ, Kilduff LP, Crewther BT, Beaven M, West DJ. Morning based strength training improves afternoon physical performance in rugby union players. J Sci Med Sport 17(3): 317-321, 2014.

15. Correa CS, LaRoche DP, Cadore EL, Reischak-Oliveira A, Bottaro M, Kruel LF, Tartaruga MP, Radaelli R, Wilhelm EN, Lacerda FC, Gaya AR, Pinto RS. 3 different types of strength training in older women. Int J Sports Med 33(12): 962-969, 2012.

16. Cox MH, Miles DS, Verde TJ, Rhodes EC. Applied physiology of ice hockey. sportsmed 19(3): 184-201, 1995.

17. de Villarreal ESS, Izquierdo M, Gonzalez-Badillo JJ. Enhancing jump performance after combined vs. Maximal power, heavy-resistance, and plyometric training alone. J Strength Cond Res 25(12): 3274-3281, 2011.

18. Edwards RH, Young A, Hosking GP, Jones DA. Human skeletal muscle function: Description of tests and normal values. Clin Sci Mol Med 52(3): 283-290, 1977.

19. Ekstrand LG, Battaglini CL, McMurray RG, Shields EW. Assessing explosive power production using the backward overhead shot throw and the effects of morning resistance exercise on afternoon performance. J Strength Cond Res 27(1): 101-106, 2013.

20. Farlinger CM, Kruisselbrink LD, Fowles JR. Relationships to skating performance in competitive hockey players. J Strength Cond Res 21(3): 915-922, 2007.

21. Fernandez-Fernandez J, Sanz-Rivas D, Saes de Villarreal E, Moya M. The effects of 8-week plyometric training on physical performance in young tennis players. Pediatr Exerc Sci (1):77-86, 2015.

22. Fernandez-Santos JR, Ruiz JR, Cohen DD, Gonzalez-Montesinos JL, Castro-Pinero J. Reliability and validity of tests to assess lower-body muscular power in children. J Strength Cond Res 29(8): 2277-2285, 2015.

23. González-Badillo J, Rodríguez-Rosell D, Sánchez-Medina L, Ribas J, López-López C, Mora-Custodio R, Yañez-García J, Pareja-Blanco F. Short-term recovery following resistance exercise leading or not to failure. Int J Sports Med 37(04): 295-304, 2016.

24. Gouvea AL, Fernandes IA, Cesar EP, Silva WA, Gomes PS. The effects of rest intervals on jumping performance: A meta-analysis on post-activation potentiation studies. J Sports Sci 31(5): 459-467, 2013.

25. Güllich A, Schmidtbleicher D. Mvc-induced short-term potentiation of explosive force. New Stud Athlet 11: 67-84, 1996.

26. Haff GG, Triplett NT. *Essentials of strength training and conditioning 4th edition*. Human kinetics publishers; 2015.

27. Hamada T, Sale D, MacDougall J, Tarnopolsky M. Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. Acta Physiol 178(2): 165-173, 2003.

28. Hamada T, Sale DG, MacDougall JD, Tarnopolsky MA. Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. J Appl Physiol (1985) 88(6): 2131-2137, 2000.

29. HARRIS GR, STONE MH, O'BRYANT HS, PROULX CM, JOHNSON RL. Short-term performance effects of high power, high force, or combined weight-training methods. J Strength Cond Res 14(1): 14-20, 2000.

30. Harrison A. Postactivation potentiation: Predictors in ncaa division ii varsity track and field power athletes. WWU Masters Thesis Collection Paper 130 2011.

31. Henriksson T, Vescovi JD, Fjellman-Wiklund A, Gilenstam K. Laboratory-and field-based testing as predictors of skating performance in competitive-level female ice hockey. Open access J Sports Med (7): 81, 2016.

32. Hodgson M, Docherty D, Robbins D. Post-activation potentiation: Underlying physiology and implications for motor performance. sportsmed 35(7): 585-595, 2005.

33. Hori N, Newton RU, Nosaka K, Stone MH. Weightlifting exercises enhance athletic performance that requires high-load speed strength. Strength Cond J 24(4): 50, 2005.

34. Hrysomallis C, Kidgell D. Effect of heavy dynamic resistive exercise on acute upper-body power. J Strength Cond Res 15(4): 426-430, 2001.

35. Janot JM, Beltz NM, Dalleck LD. Multiple off-ice performance variables predict on-ice skating performance in male and female division iii ice hockey players. J Sports Sci Med 14(3): 522-529, 2015.

36. Kilduff LP, Owen N, Bevan H, Bennett M, Kingsley MI, Cunningham D. Influence of recovery time on post-activation potentiation in professional rugby players. J Sports Sci 26(8): 795-802, 2008.

37. Klavora P. Vertical-jump tests: A critical review. Strength Cond J 22(5): 70, 2000.

38. Krause DA, Smith AM, Holmes LC, Klebe CR, Lee JB, Lundquist KM, Eischen JJ, Hollman JH. Relationship of off-ice and on-ice performance measures in high school male hockey players. J Strength Cond Res 26(5): 1423-1430, 2012.

39. Kubo K, Kawakami Y, Fukunaga T. Influence of elastic properties of tendon structures on jump performance in humans. J Appl Physiol 87(6): 2090-2096, 1999.

40. Kyrolainen H, Avela J, McBride JM, Koskinen S, Andersen JL, Sipila S, Takala TE, Komi PV. Effects of power training on muscle structure and neuromuscular performance. Scand J Med Sci Sports 15(1): 58-64, 2005.

41. Kyrölänen H, Komi P, Kim D. Effects of power training on neuromuscular performance and mechanical efficiency. Scand J Med Sci Sports 1(2): 78-87, 1991.

42. Maio Alves JM, Rebelo AN, Abrantes C, Sampaio J. Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. J Strength Cond Res 24(4): 936-941, 2010.

43. Markovic G. Does plyometric training improve vertical jump height? A meta-analytical review. Br J Sports Med 41(6): 349-355, 2007.

44. Matthews MJ, Comfort P, Crebin R. Complex training in ice hockey: The effects of a heavy resisted sprint on subsequent ice-hockey sprint performance. J Strength Cond Res 24(11): 2883-2887, 2010.

45. McCaulley GO, McBride JM, Cormie P, Hudson MB, Nuzzo JL, Quindry JC, Travis Triplett N. Acute hormonal and neuromuscular responses to hypertrophy, strength and power type resistance exercise. Eur J Appl Physiol 105(5): 695-704, 2009.

46. McLeod WD, Hunter SC, Etchison B. Performance measurement and percent body fat in the high school athlete. Am J Sports Med 11(6): 390-397, 1983.

47. Mitchell CJ, Sale DG. Enhancement of jump performance after a 5-rm squat is associated with postactivation potentiation. Eur J Appl Physiol 111(8): 1957-1963, 2011.

48. Montgomery DL. Physiology of ice hockey. sportsmed 5(2): 99-126, 1988.

49. Navalta JW, Stone WJ, Lyons S. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1, 2019.

50. Palmieri RM, Ingersoll CD, Hoffman MA. The hoffmann reflex: Methodologic considerations and applications for use in sports medicine and athletic training research. J Athl Train 39(3): 268-277, 2004.

51. Potteiger JA, Smith DL, Maier ML, Foster TS. Relationship between body composition, leg strength, anaerobic power, and on-ice skating performance in division i men's hockey athletes. J Strength Cond Res 24(7): 1755-1762, 2010.

52. Quinney HA, Dewart R, Game A, Snydmiller G, Warburton D, Bell G. A 26 year physiological description of a national hockey league team. Applied Physiology, Nutrition, and Metabolism 33(4): 753-760, 2008.

53. Raastad T, Hallén J. Recovery of skeletal muscle contractility after high-and moderate-intensity strength exercise. Eur J Appl Physiol 82(3): 206-214, 2000.

54. Rassier D, Macintosh B. Coexistence of potentiation and fatigue in skeletal muscle. Braz J Med Biol Res 33(5): 499-508, 2000.

55. Rixon KP, Lamont HS, Bemben MG. Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. J Strength Cond Res 21(2): 500-505, 2007.

56. Robbins DW. Postactivation potentiation and its practical applicability: A brief review. J Strength Cond Res 19(2): 453-458, 2005.

57. Saltin B, Gollnick PD. Skeletal muscle adaptability: Significance for metabolism and performance. Comor Physiol, supplement 27: Handbook of Physiology, Skeletal Muscle (10): 555-631, 1983.

58. Schmidtbleicher D, Haralambie G. Changes in contractile properties of muscle after strength training in man. Eur J Appl Physiol Occup Physiol 46(3): 221-228, 1981.

59. Scott SL, Docherty D. Acute effects of heavy preloading on vertical and horizontal jump performance. J Strength Cond Res 18(2): 201-205, 2004.

60. Stone MH, Sands WA, Pierce KC, Ramsey MW, Haff GG. Power and power potentiation among strength-power athletes: Preliminary study. Int J Sports Physiol Perform 3(1): 55-67, 2008.

61. Taoutaou Z, Granier P, Mercier B, Mercier J, Ahmaidi S, Prefaut C. Lactate kinetics during passive and partially active recovery in endurance and sprint athletes. Eur J Appl Physiol Occup Physiol 73(5): 465-470, 1996.

62. Tillin NA, Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. sportsmed 39(2): 147-166, 2009.

63. Tsoukos A, Veligekas P, Brown LE, Terzis G, Bogdanis GC. Delayed effects of a low-volume, power-type resistance exercise session on explosive performance. J Strength Cond Res 32(3): 643-650, 2018.

64. Twist P, Rhodes T. Exercise physiology: The bioenergetic and physiological demands of ice hockey. Strength Cond J 15(5): 68-70, 1993.

65. Verkhoshansky Y, Siff MC, Yessis M. *Supertraining*. Verkhoshansky publishers; 2009.

66. Wilson JM, Duncan NM, Marin PJ, Brown LE, Loenneke JP, Wilson SM, Jo E, Lowery RP, Ugrinowitsch C. Meta-analysis of postactivation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. J Strength Cond Res 27(3): 854-859, 2013.

67. Yang N, MacArthur DG, Gulbin JP, Hahn AG, Beggs AH, Easteal S, North K. Actn3 genotype is associated with human elite athletic performance. Am J Hum Genet 73(3): 627-631, 2003.

68. Zatsiorsky VM, Kraemer WJ. *Science and practice of strength training*. Human Kinetics publishers; 2006.

69. Zwiren L, Skinner J, Buskirk E. Use of body density and various skinfold equations for estimating small reductions in body fatness. J Sports Med Phys Fitness 13(4): 213, 1973.